


Strategic Materials

ABSTRACT: The Strategic Materials Seminar focused its study on ceramics, ferrous and non-ferrous metals, composites, and advanced materials. A series of common themes became apparent during this study. Economic engagement and assured access to the global supply of materials are critical. The United States must be capable of applying all instruments of national power, including military capabilities, to ensure that access. Ultimately, what is important is the integration of materials science and manufacturing processes. Finally, the near-term product emphasis is jeopardizing long-term research and development. It is here that the seminar has identified both the greatest potential risk to national security and an opportunity for government investment.



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Domestic:

USGS, Reston, VA
NASA-LARC, Langley, VA
ONR, Arlington, VA
Liburdi Engineering, Hamilton, Ontario
St. Gobain Advanced Ceramics, Hamilton, Ontario
GM Defense, London, Ontario
Dofasco Inc., Hamilton, Ontario
Polywheels Manufacturing, Oakville, Ontario

International:

DLR, Stuttgart, Germany
Plansee Tizit, Reutte, Austria
EADS, Ulm, Germany
Daimler-Chrysler, Ulm, Germany
ONERA, Chatillon Cedex, France
Giat Industries, Bourges, France
Euro-Shelter, Rennes, France



ICAF

INTRODUCTION

The Stone Age.

The Bronze Age.

The Silicon Age.

From ceramic pots critical to enabling food storage; to metals for swords and ships, to composites and ceramics critical to information age technology -- materials have been the basis on which technology and civilizations depend. Strategic materials have been a defining factor, not only for the technological base for civilizations and for differentiating among epochs, but also in determining the competitive advantage of nations.

What makes a material “strategic?” Is it the measure of value? Is it a function of warfighting capability, or economics, or science? When does a material become strategic? Is the list of strategic materials constant? What materials will be strategic in the future? Is there a way to predict what materials will be strategically critical?

After World War II, the U.S. Government recognized the need to stockpile materials considered critical to national security. It was imperative that the United States maintain control of the full materials cycle – from the mine, to the refinery, to manufacturing the end product. Ownership of the entire industrial base was, therefore, required. In essence, any material chain not fully indigenous was at risk. As a result, the Government invested billions of dollars stockpiling “high risk” materials during the Cold War.

Today, the global environment is very different. The world is no longer bi-polar. And for the moment, the United States has no military peer competitor. For this reason, some would argue materials are merely commodities; furthermore, even those produced by only one or two countries are readily available in the international market place.

This year, the Strategic Materials Seminar examined the criticality of a variety of materials and their relationship to national security. The seminar studied the steel, aluminum, titanium, advanced ceramics, and composites industries and produced an assessment of the current status, an analysis of the future challenges, and a proposed role for the government. This report concludes by examining three issues the seminar determined to have overarching significance: redefining strategic materials, the future of the national stockpile, and nanotechnology.

KEY INDUSTRIES

STEEL:

The domestic steel industry remains much as it has for the past several years. The major issue continues to be global production overcapacity and the resulting depression of steel prices. Some of this overcapacity is government subsidized. And while the U.S. Government has taken steps to protect the domestic steel industry from this unfair competition, the industry continues to struggle. Yet, some companies have remained competitive.

Current:

In the 1970's and 1980's, the U.S. steel industry underwent a significant period of restructuring. The industry reduced inefficient capacity by 30 percent and employment by 60 percent, invested close to \$60 billion in modernization, and increased labor productivity more than two-fold.¹ The modernization was characterized by clean, basic oxygen furnaces in integrated mills, replacing the open-hearth technology of past generations and electric arc furnaces in mini-mills, which recycle steel at a fraction of the energy and cost. The steel industry emerged as a world-class power when, in 1995, exports reached a 55-year high of 7 million tons.²

Yet the industry's euphoria ended abruptly in 1998 when steel imports exceeded exports by an all time high of 36 million tons³ due to under-priced, subsidized material from the Orient. Imports subsided slightly in 1999 and 2000 to 34.4 and 32.4 million tons,⁴ respectively, while production increased from 110.7 million tons to 114.9 million tons.⁵ Today, the steel produced annually in the United States is valued at close to \$75 billion,⁶ and domestic production satisfies 75% of domestic demand.

There are several root causes to the continuing high levels of low-priced imports. Many countries have steel-making capacity greatly in excess of demand and the cumulative excess worldwide is estimated to be 300 million tons.⁷ This excess capacity is viewed, not only as injurious, but also unfair, as much is governmentally financed.⁸ Furthermore, many countries do not have the same environmental regulatory constraints. For instance, Russian mills are older open-hearth furnaces without either pollution control systems or the investment burden and related operating costs.⁹

Finally, even though domestic capacity is below domestic demand, the industry is seeking to increase exports in their higher value niche areas, which they find to be more profitable. The U.S. steel industry seeks to ensure that they have free and unfettered access to foreign markets.

Future Challenges:

The demand for steel products over the next five years will continue to grow. The International Iron and Steel Institute predicts global steel consumption in 2005 to reach 830 million tons, some 78 millions tons higher than in 2000, a growth rate of 2% annually.¹⁰ Given these statistics, it appears that the global production overcapacity will continue to adversely affect the domestic steel industry. The consequences of this overcapacity will present challenges to both the industry and U.S. Government.

Why should the U.S. Government take any action to save the steel industry? The steel industry is a relatively small part of the nation's economy, both in terms of the

number of people employed and the contribution to GDP. And while a great number of jobs are dependent on steel production and the contribution to GDP by steel-consuming industries rather significant, that is all the more reason to allow market forces to dictate the size and structure of the domestic steel industry. The competitiveness of those steel-consuming industries and security of those jobs is predicated on the availability of high quality steel at the lowest price possible. Government interference with market forces will deliver neither.

The military component of the national security argument is also suspect. The U.S. military is anything but a voracious consumer of steel. Consider that an aircraft carrier uses approximately 47,000 tons of steel during construction.¹¹ Purchased over the four to six year construction period, that amount of steel is miniscule. Military applications don't even rate a separate entry on a steel consumption chart. While defense systems rely heavily on steel, the share of the market is so small that accessibility, in a time of crisis, is not a concern.

Equally suspect is the economic power argument. Granted, steel is the backbone of the nation's infrastructure. However, it is readily available and there is excess global capacity. Today, steel has become a fungible commodity. As such, the source is less critical than in the past. Consider the example of information technology, which is arguably an even more important element of our economic power and national infrastructure. A significant portion of the production and assembly of the hardware supporting information technologies occurs outside of the United States. If computer components can be fungible, so too can steel.

Does the steel industry need government assistance? There are many producers, both integrated steel mills and mini-mills, that have managed to remain profitable for the past three years. Under the same labor contract, using the same raw materials, and producing the same product, some companies thrive while others wallow. One significant difference is effective management that has made both hard and wise choices, sacrificed when necessary, and retained a competitive advantage.

Government Role:

The Government has a role to play in the regulation of industry, specifically in international trade. Yet, policies that interfere with the free market should be carefully considered. After discussions with industrial and governmental experts, the seminar reached a series of conclusions.

Tariffs and quotas are questionable protective measures. They fail to address the unfair government support provided to some overseas producers. Thus, if the U.S. Government is going to impose tariffs and quotas, it must do so judiciously and focus on importers who receive government subsidies or who benefit from lax environmental regulations and enforcement. Ultimately, these tariffs and quotas would burden the consumer who ultimately bears the cost of higher steel prices.

However, if the United States is averse to foreign government-provided subsidies, then it should not subsidize its own steel industry. In addition, government subsidies such as the Steel Guarantee Loan Program have a poor track record. After all, propping up under-performing producers just drags down healthier producers by contributing to the continuation of the excess global steel capacity and the resulting depressed steel prices.

Additionally, government policies should permit the continued restructuring of the industry. Those companies that are thriving under the current adverse conditions are doing so because they divested when it was necessary, merged when it made them more competitive, or took some similar restructuring action to ensure their continued viability.

Similarly, an import notification system would allow the industry to react to those conditions and allow the government to ensure importers are in compliance with fair trade standards. An internet-based system would allow all of the industry players to monitor the import situation and assist in identifying free trade violations. Enhanced situational awareness will allow both the government and industry to take timely appropriate action in response to import conditions.

Efforts by the United States to convince other governments not to subsidize excess capacity or troubled producers would assist in leveling the playing field and go hand in hand with targeted tariffs. So would efforts to open closed markets. Countries with closed markets could be recipients of an import quota . . . of zero.

Finally, the U.S. Government should vociferously enforce its trade laws and seek to strengthen world trade laws. The creation of an internet-based, real-time import tracking and notification system would enhance situational awareness and facilitate the timely response by both government and industry to evolving import conditions.

In conclusion, the dilemma is shielding the industry from unfair competition while ensuring that market forces determine which steel producers will be globally competitive.

NON-FERROUS METALS:

Nonferrous metals, titanium and aluminum, are only a small part of the \$9 trillion U.S. economy, but they are essential elements in a variety of defense systems, and their impact is felt throughout the economy. As the Department of Energy's web site states: "Aluminum has an impact on every state and community in America--either through plants and facilities, recycling, heavy industry, or consumption of consumer goods."¹²

Current:

The raw minerals used to produce titanium are available throughout the world and in quantities necessary to meet most requirements. Even without imports, the United States has titanium mineral reserves of approximately 15 million tons of ilmenite and rutile with a requirement for approximately 200,000 tons annually.¹³

With the recent closure of Allegheny Technologies (previously Ormet) in January 2001, TIMET North America is the only remaining large-scale domestic producer of titanium sponge, the key intermediate form of pure metal in the refining process. Five American companies produce the titanium ingots. Overall, the United States has a production capacity of 21,600 metric tons of titanium sponge, and 91,600 metric tons of titanium ingots. This production capacity is in comparison to 1998 domestic titanium metal consumption of approximately 21,600 metric tons and the somewhat lower 1999 consumption of 14,500 metric tons.¹⁴ The above data shows the United States has an imbalance of sponge production capacity compared to subsequent titanium ingot production capabilities. This shortfall is compensated for via a reliance on imported titanium sponge from Russia (49%), Japan (36%), Kazakhstan (8%), China (3%), and others (4%).¹⁵

Aluminum's primary ore, bauxite, is found worldwide. The U.S. Geological Survey's "Bauxite and Alumina" publication lists 27 bauxite producers; however, 50% of bauxite production comes from Australia, Guinea, and Jamaica.¹⁶

Although the aluminum industry is global in scope, it is dominated by a small number of producers. The largest aluminum companies are located in North America. Alcoa and Kaiser are U.S.-based, and Alcan is Canadian.

In characterizing the industry, it is important to note that primary aluminum production is electricity intensive. Aluminum is produced by electrolysis, and electricity represents about 40% of total operating costs and about \$2 billion annually.¹⁷ As a result, firms build aluminum smelters near cheap, available electric power sources.

Aluminum is used in a wide variety of products, including many national defense-related applications. Items related to national defense make up small portion of industry sales, but are important nonetheless. Aluminum is used in shipbuilding, aircraft production, and communications systems. The industry's major markets are transportation, containers and packaging, and construction.

Future Challenges:

The overall demand for titanium metal has continued to grow despite serious setbacks to the industry from events such as the end of the Cold War in 1991 and volatile aerospace industry sales.¹⁸ The benefits of strength and lightweight continue to make titanium a highly desirable material for both military and civilian applications, and changing technologies will allow their application at reduced cost. The industry expects a significant increase in U.S. military titanium metal use in the next decade.¹⁹

An example of future titanium military use is in land combat systems. The Army Research Laboratory (ARL) at Aberdeen Proving Ground, Maryland, is experimenting with potential breakthrough technologies that encapsulate ceramic materials with titanium. As with all products involving titanium, a significant issue is cost. Even prior to recent efforts to field the Army's immediate armor vehicles, ARL scientists were developing less expensive methods of producing low quality titanium that would be effective as armor.²⁰ As the U.S. Army's titanium armor plate quality requirements are less severe than aerospace standards, the Army has been successful in replacing components on both the Abrams main battle tank and Bradley fighting vehicle with lower cost titanium.

The U.S. Geological Survey predicts an increase in the demand of titanium metal of 5% annually over the next decade.²¹

Aluminum use in the United States is still growing, although primary production may shrink due to the impacts of energy costs. Aluminum demand will likely continue to grow, especially in automotive and infrastructure areas. The need for energy efficient, low emission cars and trucks will encourage greater aluminum use. The average car uses 250 pounds of aluminum today, but aluminum intensive vehicles could use 300-700 pounds per car by the year 2020.²²

Partnership is another key to aluminum's growth. Aluminum's future will depend on its ability to forge partnerships and expand upon existing relationships. The formation of the Aluminum Association Inc. has provided focus to the industry in charting new markets through R&D programs and services. In reaffirming this commitment, the industry joined forces with the Department of Energy's Office of Industrial Technologies

to establish the Industries of the Future (IOF) partnership. The IOF partnership identifies key challenges confronting the industry for the next two decades and establishes broad, industry-wide R&D goals. Technology roadmaps are but one of the examples of this partnership's productivity.

Technological developments will create new opportunities for aluminum applications. One example is the use of inert anodes that make aluminum production more efficient and environmental friendly. Also, bridges constructed of aluminum are stronger and more flexible, and thus better suited for increased traffic, can tolerate de-icing salts and require less maintenance. And, as one last example, vehicles made with aluminum have increased crashworthiness and safety features. These cars are better shock absorbers and have shorter braking distances.

There are ten primary aluminum production plants in the Pacific Northwest (PNW), and most are idle because of energy issues. The combination of low precipitation (affecting hydroelectric supply) and elevated West Coast demand increased market electricity prices over tenfold. "As a result, about 1.3 million tons of the 1.9 million tons per year of engineered capacity in the region has been temporarily idled and could remain closed for several years."²³ Since the PNW supplies 40% of the United State primary production, well over two billion pounds of aluminum must be replaced. However, this is not a problem given a readily available global aluminum supply. Surprisingly, there has been little change in aluminum prices since the crisis began. On the other hand, there are estimates that long-term closures could raise aluminum prices by 10%.²⁴

Government Role:

Overall, titanium metal is important domestically, but is not currently critical. As with steel, titanium has become a commodity, readily accessible worldwide. Yet, there are two aspects of the titanium metal industry requiring continuing attention.

First, the United States is only one company away from being completely removed from the titanium sponge producing business. While there is no indication, at this time, that TIMET's modern titanium sponge production facility is going to go out of business, its condition should be monitored. If TIMET were ever to totally close its sponge production capability, the Government might consider that loss a strategic risk. While in today's globalized titanium markets this is not an issue, there should be some attention to the potential loss of the technological and experience base.

Secondly, titanium minerals are readily available, but titanium metal use is limited by the cost of an inefficient production process. This is a potential area for government supported basic research to better understand titanium and potentially less expensive methods of processing. Titanium metal is produced in a manner technically unchanged since 1948, and a breakthrough in production methods, resulting in cheap titanium metal, would reap great benefits for society.

Governments suggested role in the aluminum industry is altogether different. Based on discussions with industry and government representatives, the seminar concluded that the federal government should not bail out the Pacific Northwest aluminum producers. While California's energy policies have contributed to the current crunch, many aluminum plants are inefficient. Consequently, some aluminum producers are likely to move to cheaper locations abroad. Other producers will stay in the area,

build new power plants, and modernize smelters. From a national security and an economic perspective, it will not hurt our strategic position if more aluminum production moves off shore.

ADVANCED CERAMICS:

The United States has a continuing need for materials that are lightweight, very strong, resistant to corrosion, energy efficient, and can operate at high temperatures. Advanced ceramics are emerging as a new generation of materials that have these properties. Advanced ceramics consist of carbides, pure oxides, nitrides, non-silicate glass and many others. These advanced materials are increasingly used in industrial and highly technical applications.

Current:

Advanced ceramics influence nearly every known industry in some capacity. The vast electronics industry would not exist without oxide ceramic microwave filters, resonators, or oxide electrodes for lithium batteries.²⁵ Numerous systems on the Hubble Telescope rely on electric ceramic components. The technological breakthrough in telecommunications in the past decade is directly attributable to glass optical fibers that comprise the backbone of the high-speed Internet. Replacement of hard tissues of the body (e.g. bone and teeth) is possible, in large part, due to bioceramics. In addition, ceramic components are being tested for use in lighter, more fuel-efficient aircraft, which could lead to entirely new aircraft designs due to reduced weight and fuel consumption.²⁶

In 1974, the entire U.S. ceramic industry was estimated at \$20 million. In recent years, it has grown to over \$35 billion.²⁷ Furthermore, the 150 largest ceramics companies worldwide had combined revenues of \$175 billion last year.²⁸

Future Challenges:

Although traditional ceramics have well-established markets for specialized application, the emerging potential of ceramic matrix composite and other advanced composites materials offers unprecedented property attributes and design versatility. Electronics ceramics engineers are pursuing technological advances that will turn nonfunctional packing parts into functional components of the devices. Similarly, opto-electronic integrated circuits for the telecommunications industry will likely be fashioned out of ceramic materials. High temperature superconductors may one day open the door to magnetic levitation vehicles. And, medical technology is expected to increase the use of ceramic components with improved strength, nonreactivity, longevity, compatibility, porosity, and cost.²⁹

Concerns over catastrophic failure, due to mechanical stress or thermal shock, motivated the Department of Energy to spearhead a program specifically designed to collaborate on continuous fiber ceramic composites, or CFCCs³⁰. These specialized ceramic matrix composites can overcome the lack of toughness and thermal shock resistance inherent in traditional ceramics by embedding fibers into the material, creating a new generation of materials for use throughout industry. Moreover, ceramic matrix composites' most desirable characteristics are retained--high-temperature stability, light weight, nonmagnetic/nonconductive properties, and structural versatility. Application potential for these advanced ceramic composites is widespread, particularly for high-

energy use process industries such as steel, glass, aluminum, chemical and the forest products industry, as well as aerospace, transportation, and defense industries.

Hybrid systems (combining metals, plastics and refractory ceramics) are demonstrating improved reliability, wear, corrosion and temperature properties. The benefits of using CFCCs in manufacturing processes include increased energy efficiency/ environmental compliance and enhanced productivity. Due to increased emphasis on global competitiveness, energy efficiency, and regulatory compliance, industries must aggressively explore the emerging advantages of ceramic composites.

Although uses for advanced ceramics are wide and varied, their use in communications-electronics will be particularly critical. As electronic devices get smaller, the properties of advanced ceramics become even more beneficial to product design. Lightweight, heat-resistant, resilient materials are critical for advances in the miniaturization of integrated circuits. Progress in communications-electronics is contingent upon making devices smaller and faster; ceramics could be the key enabling material in this area.

Advanced ceramic applications in fiber-optic technology will play a crucial role as the demand for broadband communications increases. Applications such as streaming video, telemedicine, telemaintenance, new internet-based music formats and unified messaging will demand the additional bandwidth that only fiber optic cables can deliver. One of the leading edge IT breakthroughs, Dense Wave Division Multiplexing (DWDM), will also expand the need for fiber optics. This technology is able to break the light running down a fiber into hundreds of colors, (soon to be thousands) each representing its own frequency. The result will be orders of magnitude increases in bandwidth. Optical switches are being developed which will actually switch light in the core of the Internet to produce amazing bandwidth improvements. Optical networking will also drive up the demand for fiber optics.

However, reaction to advanced ceramics is not unlike many other emerging specialty materials. Consumers and members of industry are reluctant to embrace advanced ceramics due to pressures from profit-oriented stockholders, bias toward the use of traditional materials (steel and aluminum), and excessive production costs. Also, lack of uniform technical standards, insufficient design and test experience, along with inadequate specifics about material properties, contributes to this reluctance.³¹ Additionally, the ability to train and recruit quality talent is a problem that has been evident for at least the last five years. This will continue to affect both the quality and the cost of labor.

Import pressure is constant, primarily due to Japan's ability to meet market needs better than the domestic ceramics industry. Environmental, health and safety standards are areas that also need improvement. Despite the growing advantages of advanced ceramic materials in reducing energy consumption in some manufacturing processes, the ceramics industry is one of the most intensive users of energy in the world, and as a result, generates around twenty million tons of carbon dioxide (CO₂) annually. However, recent developments such as microwave-assisted gas firing could cut CO₂ emissions by as much as 50%.

Government Role:

Several conclusions emerged from research and discussions with industry representatives and government experts. The government should encourage materials research, improve consumer confidence and encourage industry-wide capital investment for long-term applications. Furthering government/private industry cooperation through sharing of data and consortium development should strengthen commercial potential and expand advanced material uses within other markets.³² Efforts to publicize ongoing government applications of advanced ceramics (e.g., use of advanced ceramic armor plating in weapon systems) are likely to encourage commercial confidence and acceptance.

Given balanced incentives from government and free market trends, the advanced ceramics industry has the potential to transform existing material/product markets, changing industries around the world for the better.

COMPOSITES:

Due to their expense, complex composite materials were initially used in national defense and aerospace applications. Though still of great importance in these areas, growth outside of this historical niche appears to be on the verge of a sizable expansion.

Current:

As DOD budgets, especially R&D, declined during the 1990's, many defense-related industries expanded into the civil sector in order to remain in business. The composites industry was no different. The consequences for composite materials have paralleled those of other industries – market share competition that was already tough became even more brutal. The result has led to keen competition to make materials stronger, lighter, more durable, environmentally friendly, and of flexible design available at lower cost to the customer. The composites industry has provided many new materials alternatives to end-users. Representatives from the steel and aluminum industries acknowledge that competition from composites is fueling the drive for improved product quality and production processes, reduced costs, and an increased customer service focus.

According to Composites Fabrication Association (CFA), an advocates group for the composites industry, there are “approximately 2000 composites manufacturing plants and materials suppliers across the United States which employ more than 150,000 people.”³³ In addition, the entire composites industry contributed over \$24 billion to the nation's economy in 1999.³⁴

As previously mentioned, the defense and aerospace industries were once the main clients of the composites industry. However, government purchases and R&D funding have diminished significantly in recent years. Nonetheless, commercial R&D coupled with more focused government funds and the entrepreneur spirit continues to yield new applications and fabricating processes for composites.

An example of the innovative approaches of government engaging the science and technology commercial sectors is the DoD Dual Use Science and Technologies program. A focus area approved for the program this year is a proposal by the Army to develop new commercial technologies that will enable affordable, lighter and more fuel-efficient trucks.³⁵ Corrosion resistance and durability are also desired – both characteristic of composites. Obviously, this presents an opportunity for the composites industry to make further inroads into both the automotive and defense industries.

Albeit at a slower pace, defense research and development facilities continue to refine composites applications despite funding reductions. A key technology enabler for stealth and space structure applications, composites are studied and applied extensively through the Air Force Research Laboratory at Wright-Patterson Air Force Base, Ohio. Reports of the Defense Secretary's ongoing review of the military indicate the potential greater need for planes, ships and vehicles with stealth capabilities to counter the proliferating Third World missile threat.

The composites industry sees opportunities in many defense and aerospace sectors, not the least of which is the recently revived U.S. missile defense system. In addition, within the military and commercial aircraft industries, the expectation is that increasing amounts of advanced composites will be used. Satellites and launch vehicles are the next biggest market for advanced composites.

Composites are also used in infrastructure applications. Our nation's infrastructure is aging and falling into disrepair. The composites industry is competing for the hundreds of billions of dollars that the government spends to improve or repair this infrastructure. Fiber reinforced polymer (FRP) composites infrastructure construction has been demonstrated. For instance, all-composite road bridges are in place and serving vehicular traffic, to include fully loaded 18-wheel tractor-trailers, daily. In addition to pedestrian and vehicular bridges, composites are used as reinforcing bar for concrete, pilings for waterfront structures, and in seismic-related construction.

By far, the largest civil use today of composite materials is in transportation, and in the automotive industry in particular. It accounts for 32 percent³⁶ of all demand. Material substitution in automobiles is expected to continue to favor composite materials.

The next largest commercial use of composites is home construction. Whether it is new home starts or home remodeling and improvements, the composites industry is linked closely to the homeowner. Commercial marine use, once the industries largest, is now tied with corrosion use as the third and fourth largest segment of the industry.

Future Challenges:

Forecasts for the composites industry correlate closely with those for the overall economy since the industry services many of the mainstream economic sectors.³⁷ Therefore, industry analysts are predicting a slowing growth in 2001 to 1-3 percent with a resurgence of 4-5 percent in 2002-2003. Growth has averaged 6-7 percent per year since 1960.³⁸

From making composites from biodegradable materials to the marriage of cutting-edge nano- and smart-technology with composites, the industry's future looks bright. Smart technology sensors embedded in a composite are already in use. Expect to see more diagnostic and data collecting smart sensors in composite applications – especially where a product's material integrity equates to safety issues.

Another equally important future aspect of the industry is in manufacturing processing. Reducing the costs to make composites has a lot to do with how the material and its end products are manufactured and finished. Certainly, IT and CAD applications have been and will continue to be incredibly useful tools in this industry. However, industry specific improvements include processes such as vacuum-assisted resin transfer molding (VARTM). VARTM allows more cost-effective manufacturing of large

composite structures. Continuing advancements that eliminate steps in material fabrication will help drive prices down for the customer.

Yet, continuing challenges to the composites industry are the high costs of material handling, capital equipment, manufacturing³⁹ and educating traditional metal users and the nation's leadership on the use of composite materials. As discussed, improvements are being made in equipment and manufacturing. With regard to education, the industry has pulled together to get the word out. Strong advocate associations exist – CFA and Market Development Alliance of the FRP Composites Industry (MDA) are but two examples. The CFA has recently hired additional personnel specifically for a new grassroots effort to educate congress on the benefits of composites and advocate policy issues.

Research indicates that the top government policy issues facing the industry are related to environmental protection. This is not surprising. After all, composites are a part of the chemical industry and, as such, receive a great deal of attention from regulators. For instance, the EPA is about to enforce regulations that would require the capture and control of 95 percent of hazardous air pollutants from plants, large and small – a requirement CFA claims to be “technically infeasible and unaffordable.”⁴⁰

Other challenges for the industry include the need for standards of use for new materials and the requirement for regulatory agency approval of new products. These two issues affect liability issues in the auto and aircraft industries for example. Therefore, more performance data is needed before breaking into some markets. Interestingly, the gradual phase out of military specifications and the increasing use of COTS products may actually work against establishing standards for composites.

Government Role:

Not unlike most other industries, there needs to be careful consideration of the costs and benefits of environmental regulation. Excessively stringent and costly standards could force some business shutdowns or relocation overseas and slow or curtail innovative development. Government and industry must continue to engage each other and determine the appropriate balance of this issue.

Government can play a significant role in developing suitable standards. In the many defense and combined defense/commercial programs, engineering performance database development and information sharing would aid in the establishment of material standards. A government military laboratory should be assigned management and oversight of defense and dual use program data collection, fusing and access to further standards measurement and development.

OVERARCHING ISSUES

Redefining “Strategic Materials:”

There is a growing need to focus on future aspects of materials in relation to other technologies. This essay looks at the information age impacts on the strategic materials industry. With all the difficulties encountered in attempting to define the industry in an appropriate context, now may be the time to redefine what it means to be a strategic material. Traditionally, materials have been separated into certain generic categories. These categories stem from an evaluation of the materials viewed as contributing most

greatly to the national and world economies. There is a lot of research occurring that integrates materials with other technologies such as information and biology. Perhaps the integrated materials systems that result should be the next generation of strategic materials. Already, there is a great deal of reference made to special materials known as designer materials.

At the leading edge of materials science today there are materials being tailor-made with new properties using innovative processing techniques. Smart materials, a type of designer material, tend to include integrated sensors, actuators, and electronic controllers that create new functionality, such as vibration control and health monitoring. One approach used to develop smart materials is to “create” composite materials from known structures, then embedding active elements such as sensors. Another approach involves totally manufacturing new materials at the atomic and molecular levels with already built-in smart functionality.

Examples of smart materials applications already in use include snow skis embedded with hybrid ceramic materials to dampen vibration and eyeglass frames made of “memory” metal alloys that return to their original shape when a certain temperature threshold is exceeded.

A recent study forecasts that the domestic market for smart materials applications will grow to \$273 million in 2003 with an average growth of 15 percent per year. Medical use of smart materials applications will experience the largest growth rate, nearly doubling the market for use in that field by 2003. Integral to the shift to smart materials will continue to be the rapid increases in computer power. By applying the latest information technologies, it is becoming easier to model and simulate the materials first before manufacturing them.

Moving into the information age is not without challenges. Designer materials tend to be niche applications; therefore, costs are an issue. Data storage and flow are another challenge. The basic concept of using mass amounts of miniature sensors implies that there will be a great need to handle the resulting data. The computer science field views the use of micro-electromechanical systems, or MEMS, as a huge challenge because the amount of data produced is so large and so distributed. Another challenge involves the public, which is reluctant to accept technology that is a little too much on the cutting edge (e.g. biological research, cloning, genetically modified agricultural products).

In the opinion of the seminar, the appropriate role for government is best exemplified in the Defense Advanced Research Projects Agency (DARPA). Simply put, DARPA acts as a “venture capitalist” for DOD. Other government entities must then make sure they leverage off the findings, develop them, and apply them where appropriate. With all the emphasis on materials systems, it may be time to consider referring to the industry as the strategic materials systems industry.

The Future of the National Stockpile

Despite an acute increase in America’s reliance on foreign sources in the area of strategic and critical materials, the nation’s stockpile of strategic and critical materials has been routinely downsized each year since the end of the Cold War. Initially established in 1939, the National Defense Stockpile (NDS) was intended to provide for the acquisition and retention of stocks of various materials considered essential in time of

war or national emergency. After the collapse of the Soviet Union, the absence of a credible global competitor dramatically reduced the threat of disruption to strategic material supply lines, and afforded the United States virtually unfettered access to critical resources – worldwide. This new global strategic landscape obviated the need for a large and costly strategic material stockpile. At the height of the Cold War, America's stockpile inventory was valued at over \$12 billion.⁴¹ Today, the total market value of the remaining commodities in the stockpile is estimated at \$3.4 billion.⁴²

The National Defense Stockpile remains a viable means of ensuring the availability of strategic and critical materials when confronted with the threat of geopolitical instability and/or economic disruption. A comprehensive analysis of the stockpile is necessary, however, to ensure only those materials considered essential in time of war or national emergency are maintained at sufficient levels in the stockpile -- consistent with current National Security Strategy objectives and budgetary realities. Current defense budget trends and a reduction in the threat of a protracted, large-scale war point to the need for a leaner, properly structured stockpile, consisting only of those materials that are of absolute military necessity or hold considerable promise for the future.

If the National Defense Stockpile is to serve its purpose in the new strategic environment, then DoD must abandon the “business as usual” approach and seek to shape the stockpile in order to posture America's armed forces to meet the challenges of the future. Clearly, there is a need for a process that continuously analyzes materials developments and materials processing.

The relationship between the United States and its resource-rich foreign suppliers is one of symbiosis. The U.S. is inextricably linked to those nations in which critical materials resources reside. Conversely, supplier-nations are inextricably linked to America and its robust, resource-intensive economy. Recognition of this relationship makes *access* to strategic and critical materials the overarching strategic imperative that should inform and guide our national security strategy and foreign policy decisions. And, if access is critical, then strategic reach is imperative. The United States must be willing and able to use all elements of national power, to include a highly capable military, to ensure access.

Nanotechnology:

Nanotechnology, the engineering of sub-microscopic structures, has the potential to revolutionize the materials industry. Self-healing materials are a prime example of an application for nanotechnology. Self-healing materials have biological properties imbedded into them. Science is able to mimic nature in order to create a biological response within a material.⁴³ This is accomplished by examining how a natural organism self-repairs when damaged, recreating that ability in the laboratory, and then mimicking those properties.

The John A. Volpe National Transportation Systems Office is aggressively pursuing the application of this technology within the transportation infrastructure. They are looking for smart materials that will include both sensing and self-repair properties. They cite applicability within four main areas: information technology, materials and manufacturing, aeronautics and space exploration, environment and energy.

Examples of information technology applications include unmanned vehicles for both civil and defense use, advanced communication, and sensors that continually monitor the condition and performance of infrastructure, vehicles and operators.

Aeronautics and space exploration could use nanotechnology for low-power, radiation-hardened computing systems for autonomous space vehicles, tiny instrumentation for microspacecraft, and advanced avionics.

Environment and energy applications could use nanomaterials that replace metallic components in cars. Materials developed could reduce carbon dioxide emissions significantly and replace carbon black in tires.

Potential applications for the materials and manufacturing include nanocoating of metallic surfaces to achieve super-hardening, low friction, and enhanced corrosion protection and materials for vehicles and infrastructure that could monitor, assess, repair themselves.

NASA and DARPA are both investigating the use of nanotechnology applications for future defense systems. NASA is focusing primarily on space applications - from space stations and space vehicles to space suits and biomedically engineered properties for human health. DARPA's interests are more varied. In addition to space applications, they are also pursuing ecoskeletally-enhanced suits for soldiers and chemical-biological protection gear that sense and repel chemical and biological agents. In addition, if the agent penetrates the protective gear, an antidote is administered in response.⁴⁴

CONCLUSION

As the United States Government ensures the security of the nation and promotes the welfare of its people, it must compete for the world's resources in the global market place. Therefore, **access** to the world's material resources should become an over-arching strategic imperative that shapes foreign policy decisions. In today's global environment, sustained materials access requires reliable economic alliances & partnerships designed to aid in the production, manufacture, and marketing of those materials.

Economic engagement has manifested itself in the integration of economies across national borders, increased international trade, and increased investment in foreign markets. The materials industries and economies of the world are interconnected to an unprecedented degree. As the leading consumer of natural resources, the United States must continue to leverage its position to encourage the development of stable and efficient free market economies.

Moreover, changing demographics and revolutionary technologies will intensify the global competition for the world's finite material resources. As social, political, and economic instability continues to plague many of the mineral-rich countries of the world, the United States must be prepared to respond to potential disruptions in the global materials marketplace.

In that light, the U.S. must be capable of applying **all** appropriate instruments of national power -- including military power -- to ensure access to currently unanticipated strategic materials markets.

In today's global economy, the U.S. Government has unfettered access to the world's material resources. On the macro level, the seminar concluded that no single

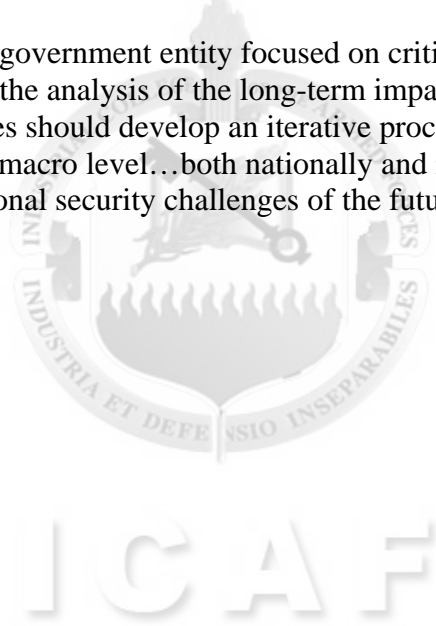
material or group of materials constitutes a vital national interest. On the other hand, the combination of materials, the associated processes, and end uses **are** critical to national security. More simply put, the relevant issue is not the specific materials used, but rather the understanding of these materials and an ability to leverage and integrate the specific desired properties of each.

The importance of advanced materials and their processing to the security of our nation cannot be ignored. Tomorrow's material applications are limited only by the ingenuity of engineers and scientists.

In both industry and government, increased emphasis on both problem solving and product fielding has dramatically shortened the research & development horizon. This near-term focus may have undesirable implications for new materials development and could eventually present national security risks in the future. The seminar observed this trend not only in North America, but in Europe as well.

Therefore, it is of vital importance that the United States invests in long-range materials research and development, both through government programs and industry partnerships.

Finally, there is no government entity focused on critical materials development, process improvement, and the analysis of the long-term impacts of each on national security. The United States should develop an iterative process to analyze material & process developments at a macro level...both nationally and internationally, to posture our nation to meet the national security challenges of the future.



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